IoT: The Big Picture 2019

Abstract:

This report provides a strategic view of the IoT market and highlights the mega-trends that boost its growth and others that hinder its growth. Developments in wireless technology, computing architecture, business models, and data analytics are considered in a hype-free examination of the market for Connected Devices (the broader market) as well as more narrowly defined IoT Devices. Shipment, installed base, and revenue forecasts through 2024 are broken down by multiple technical factors, by business model and customer type, and by vertical market and application.

MOBILE EXPERTS

October 2019

IoT—The Big Picture 2019

FIGURES

CHARTS

IoT—The Big Picture in 2019

MEXP-IOT-19
October 2019

1 EXECUTIVE SUMMARY

The Internet of Things emerged as a concept with extremely high expectations: wild estimates of IoT device growth have ranged from 20 billion to 50 billion devices in 2020. As we write this report, 2020 is only two months away but we are far from 20 billion devices.

Why has growth been slow? The connectivity works great, and new formats such as NB-IoT, LoRa, and Cat-M provide the long battery life and long range connectivity that we need. But the applications for widespread adoption are slow in coming together. Consumers use some devices such as FitBit fitness trackers and bike rental devices. But each device and application is developed separately, with a team of engineers dedicated to marrying the device and network hardware with a software stack to interpret the data.

It's not rocket science, but every new app must be developed in a similar way, with a significant investment of developer talent. The IoT connectivity is mature enough, but the platforms and APIs are not mature enough to enable somebody to quickly slap together a unique IoT use case in an afternoon.

This report examines the fundamental growth drivers and barriers facing this market, and provides a more sober view of realistic growth potential in the IoT space.

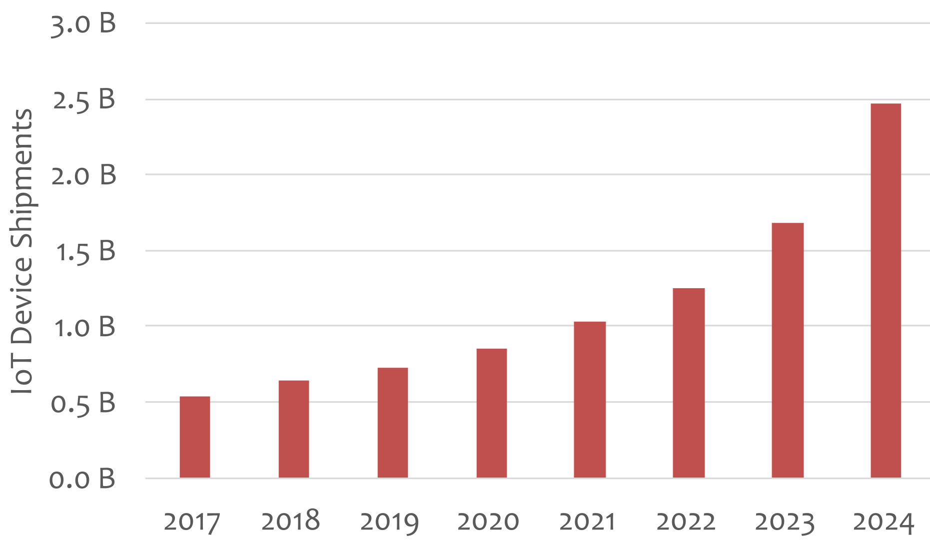

Chart 1: IoT Device Shipments, 2017-2024

Source: Mobile Experts

Here are our high-level observations about the IoT market:

- Connectivity is ready for prime time in most mainstream applications. New high-reliability, low-latency formats will emerge soon to add to this mature element.
- The enterprise market is the most significant source of demand, with the potential to drive much higher dollar value than the consumer market.

- Edge Computing platforms and Cloud platforms for non-real-time applications are now the critical part of developing the IoT market. Ease of use in IoT app development is the single biggest hindrance to market growth.

Excluding RFID devices, the installed base of IoT devices will grow from The number of IoT devices will grow from 3 billion in 2019 to 8.5 billion in 2024. RFID adds significant numbers as well but we don't count those as IoT devices. We also don't count earbuds, garage door openers, keyfobs, or any other devices which are 'human use' devices. Our definition of IoT devices limits our forecast to devices which exchange more than their own identity…they either sense data and report it, or act upon commands sent from the network.

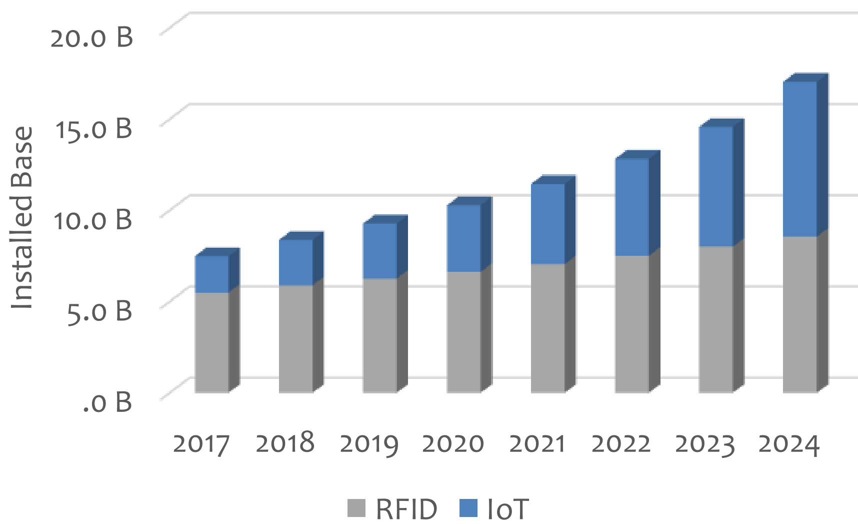

Chart 2: Total Installed Base, IoT and RFID, 2017-2024

Source: Mobile Experts

Device shipments are fairly evenly split between consumer and enterprise applications, but the revenue for enterprise IoT will be much higher. The applications for industrial markets will drive much higher revenue than simple consumer devices.

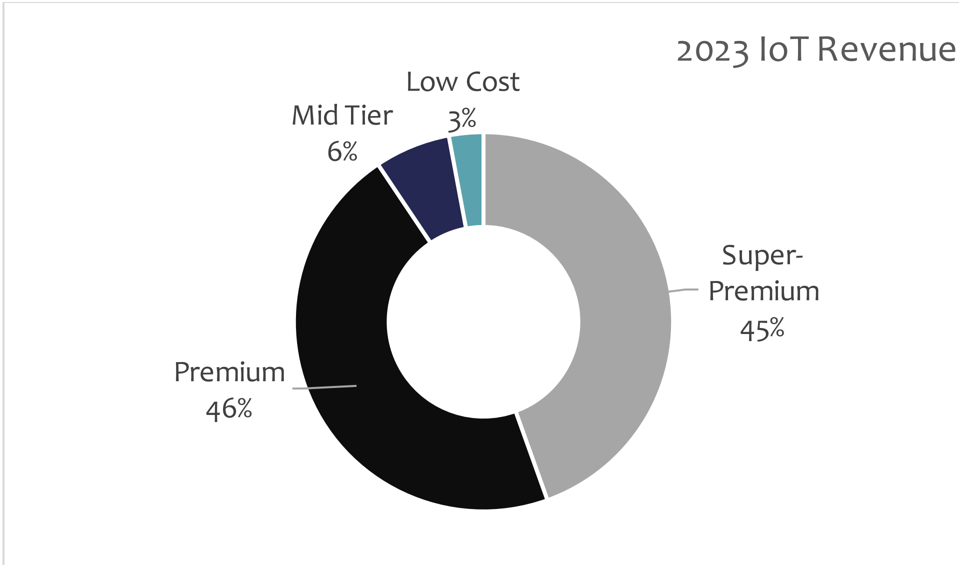

Chart 3: IoT Service Revenue: Breakdown by Tier in 2024

Source: Mobile Experts

2 MARKET DRIVERS

Many people have assumed that the growth of the IoT market was guaranteed….that the pent-up demand for automation would cause the market to explode with the arrival of long battery life. Three years ago, we disagreed and predicted a slower rise of IoT adoption.

Our conservative view has now been proven to be correct. The driving forces of consumer convenience and industrial automation/cost savings are absolutely real. But adopting IoT is a lot more complicated than simply connecting a sensor.

Mobile operators have used 2018 to bring their IoT management platforms to maturity. China Mobile has the biggest one: Their "CM IoT" platform hosts more than 500 million IoT devices currently, with an estimated 80 million using licensed cellular bands. The vendors are supporting this kind of management platform, with Ericsson, Huawei, Nokia, and ZTE all offering a variation on the IoT management platform.

The next step must be improvement in the library of open APIs that developers can use to easily plug their application into the IoT network. Today, China Mobile has 34 open APIs for various applications related to smart parking, agriculture, laundry machines, drones, smart meters, and others. This library must expand to tens of thousands of easy-to-use extensions so that small-scale app developers can quickly formulate an application.

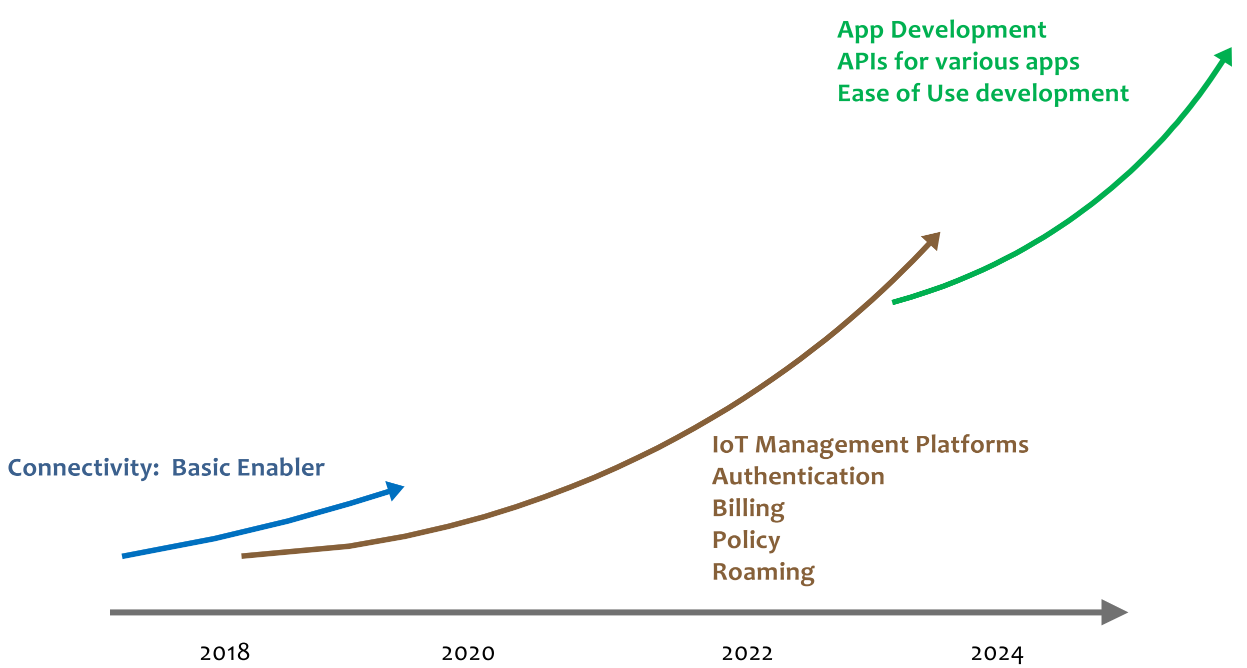

Figure 1 IoT Market Development: Two Major Steps after Connectivity

Source: Mobile Experts

On the positive side, the extreme fragmentation of the IoT market is dropping away. Niche formats such as Sigfox, RPMA, Weightless, and LTE Cat-0 are forgotten. The winning connectivity formats have emerged, with LTE-M, NB-IoT, and LoRa leading the pack for growth in wide area applications.

GROWTH DRIVERS AND INHIBITORS

The pent-up demand for IoT connectivity is strong, and low-cost, long-battery technology is available. Why isn't the market growing faster? The ease of development is the single biggest inhibitor to success. Here's a breakdown of how specific factors come into play:

- Connectivity technology is ready. LTE-based formats and LoRa have been standardized and productized, and cost has come down to target levels. These technologies offer long range with very low power consumption for battery-based devices.

- All-IP based mobile networks are in place and waiting for the devices.

- Oerators have saturated the smartphone market, and are now seeking growth in enterprise/IoT markets. (Market "push")

- Enterprises are looking for cost savings and productivity enhancement through automation. (Market "pull")

- The main remaining hindrance: Open APIs that are tailored for specific enterprise applications are not mature. Either cloud-based databases or edge-computing platforms must reach a level where an IoT application becomes easy for a developer to punch out in a day or two. If a team of 20 people is required to work for six months on an application, the barrier is too high for a nichey application to reach the market.

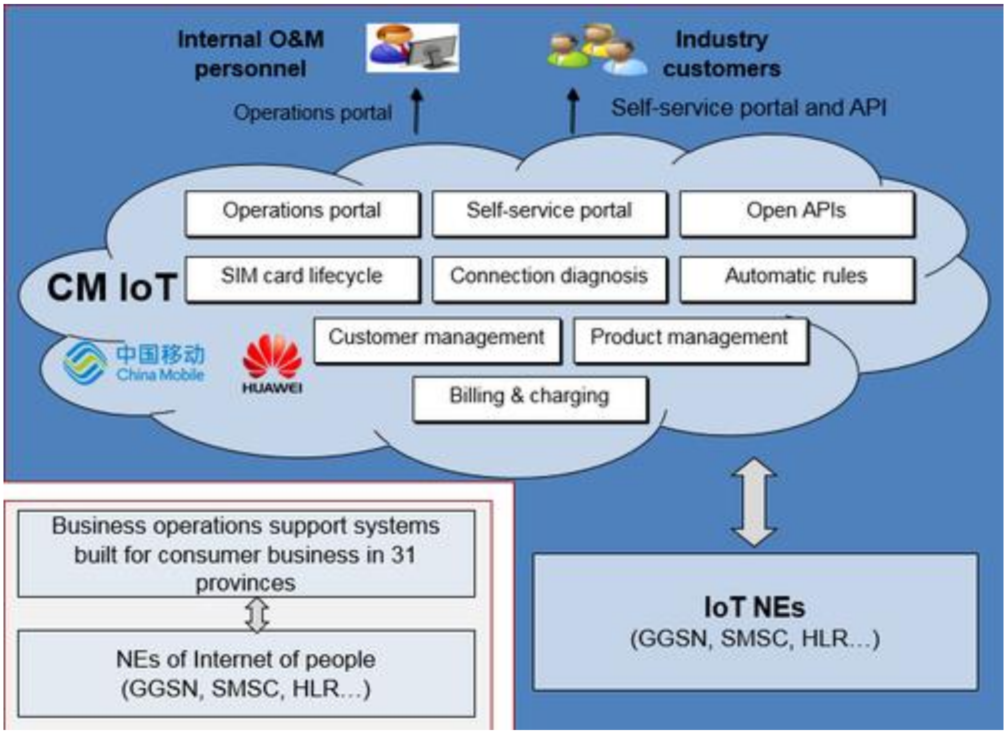

Figure 2 China Mobile's IoT Management Platform Overview

Source: China Mobile

Overall, the pieces are coming into place but the APIs and troubleshooting algorithms are not mature enough for small developers to quickly enable a new app. The ease of use is still about 1-2 years away from an ability to "go viral", where thousands of lightly trained developers can directly launch a new IoT device.

WHAT'S THE IMPACT OF 5G?

The wider audience in the tech world assumes that 5G will be the enabler for "billions of IoT connections". Somehow these billions of devices will all be cheaper than today's 4G IoT devices, but also take advantage of low latency for premium applications. This is extremely confusing for anyone that tries to think rationally about 5G, because the low cost and large number of connections are directly opposed to the high data rate and low latency characteristics.

1. High Connection Density: 5G offers the opportunity to connect a large number of IoT devices on a single radio access point. In this way, 5G is unique in its ability to reach extremely high connection density. LoRa, Bluetooth, Wi-Fi, NB-IoT, and other formats will all saturate in the range of hundreds to thousands of devices per node. But 5G NR can be configured for hundreds of thousands of devices in simultaneous connection.

2. Low Cost: It's difficult to imagine that any 5G IoT device will be substantially cheaper than NB-IoT modules. The 5G NR waveform is not substantially less complex, so the step from 4G to 5G is not likely to result in cost savings dropping by 90% as indicated in the press. Volume will have a much bigger impact than the step from 4G modem to 5G modem.
3. Low Latency: New applications in many industrial markets will be enabled with the use of low-latency wireless connectivity… so in this way, 5G NR will be very useful and unique. Note that many robotic applications that are connected by wires today can be moved to wireless, so there's an existing industrial market that already produces revenue in the billions of dollars. We expect the market changeover from Ethernet or Fieldbus to be slow, but in 20 years the low latency IoT will be significant.
4. High Reliability: With 5G, mobile operators have the opportunity to guarantee a connection to 99.99% (or possibly 99.999%) certainty. This should open up additional long term applications with premium pricing.

INFORMATION AUTOMATION

The IoT is the culmination of a very long 200-year process of industrialization. People have been gradually automating industrial processes for a long time, with greater sophistication as new technology allows. During the past 15 years we have seen ongoing automation in factories and robotics, but also a great deal of new automation in data gathering.

Since the 1950's, the electronics industry has been applied to automation in manufacturing. Some simple products have not changed very much, but manufacturing them has become far cheaper than in 1950. Consider a simple product such as a mailbox. In the past, the sheet metal would be rolled manually, cut manually, welded together manually, then painted manually. The cost in 1950 was the equivalent of a day's wages. Today, the entire mailbox can be produced with automated sheet metal, welding, and painting machines. The cost is roughly the equivalent of one hour's wages.

The primary thrust of the Internet of Things is to extend this productivity growth to the next level. Here are some examples:

- Buildings have automated air conditioning systems, but in the past have relied on human intervention when a window is left open. Sensors and automation can eliminate the need for human oversight and intervention.
- An oil well is often automated so that the pump itself can run without an attendant. But information about the level in the oil holding tank is often unavailable—requiring a technician to drive to the site, look into the tank, and verify the level. Clearly automation can save money in this case.
- Security guards are often used to manually check the status of doors and windows. A human being walks through the building to verify that doors and windows are

closed and locked. Automation can reduce the number of security personnel required in the building.

- Smart "trash cans" that notify technicians when they're full can improve efficiency in waste operations.
- Warehouses don't need to be shut down with workers physically counting every item in inventory, if inventory accuracy is high enough.

The common idea throughout many different examples is that IoT sensors can eliminate wasted time for employees. An incredible amount of time is spent on simply moving a person to a specific location so that he/she can verify very simple information. The IoT automates the process of collecting information.

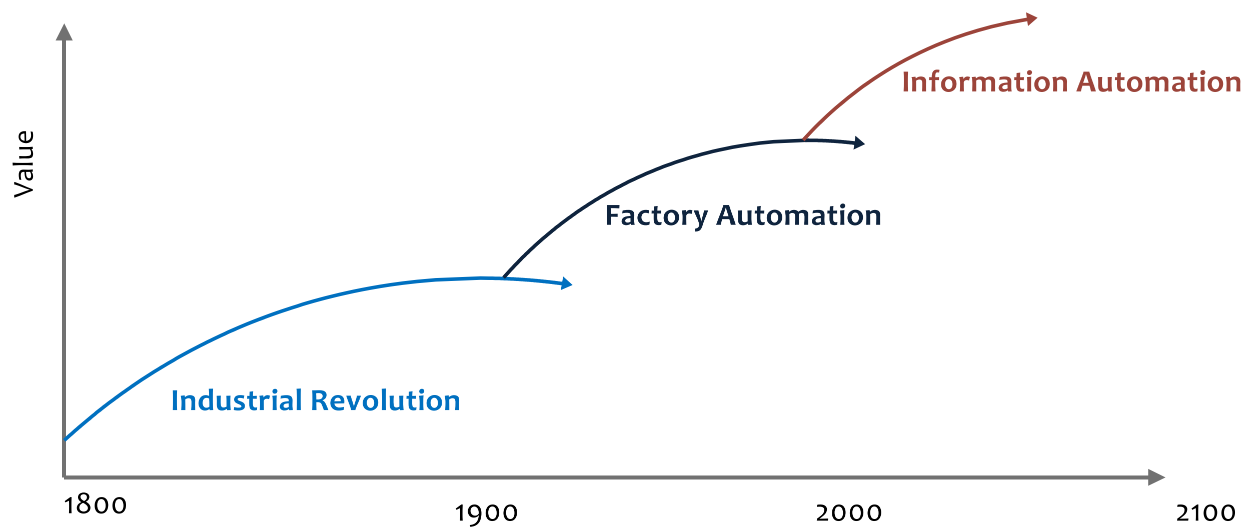

Figure 3 The next Industrial Revolution: Information

Source: Mobile Experts

We estimate that more than 70% of IoT applications center on a form of "Information Automation". The IoT device generally includes a sensor and a simple computing platform to package the data and send data along to the cloud. This is the most prominent feature of the IoT.

The secondary purpose of the IoT is to automate real-world actions. The electrical grid will have thousands of sensors to measure performance factors, but it will also include a small number of switches or other actuators that take action under dangerous conditions. A surge in power may happen too quickly for human operators to react, so actuators can divert power or shut down vulnerable equipment.

WHO'S DRIVING THE IOT MARKET: CONSUMERS OR ENTERPRISES?

Consumers have driven the mobile market for years, but expecting consumers to drive the IoT market would be a mistake. Looking at the revenue available from enterprise IoT applications and consumer IoT applications, it's clear that the industrial IoT market will dominate the service revenue. This year, over 80% of device revenue will come from business customers, not government or consumers.

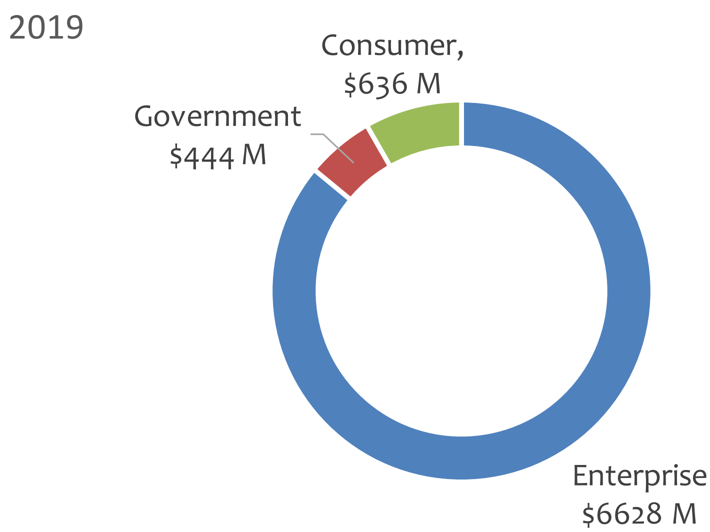

Chart 4: Breakdown of Enterprise, Government, Consumer IoT device revenue in 2019

Source: Mobile Experts

The enterprise dominates the revenue picture because enterprises have a more compelling return on investment here. Enterprises need to automate operations to save money. Consumers will automate for convenience—after all, we have washing machines, dishwashers, and other appliances—but consumers don't need to automate information at the same level as an industrial operation.

NEW STANDARDS WILL NOT DRIVE IOT GROWTH

Many people in the wireless telecom business are accustomed to fresh growth with every new generation. When 2G infrastructure was deployed, everyone bought a new 2G phone. 3G enabled new apps and everyone bought a new 3G phone. 4G was even better, so everyone bought a 4G phone. This cycle works because the infrastructure is deployed in 8 year cycles, but the replacement cycle of a phone is only about 2 years.

But in IoT, the life cycles are completely different. Enterprises that consider investments in IoT devices are horrified to think that there may be 6-8 technology changes during the life cycle of a product. The diagram below illustrates this idea: a smart meter will be in the field for 20 years, with a possible battery change after 10 years. Water and gas utilities won't like standards that change 10 times during the life cycle of a product.

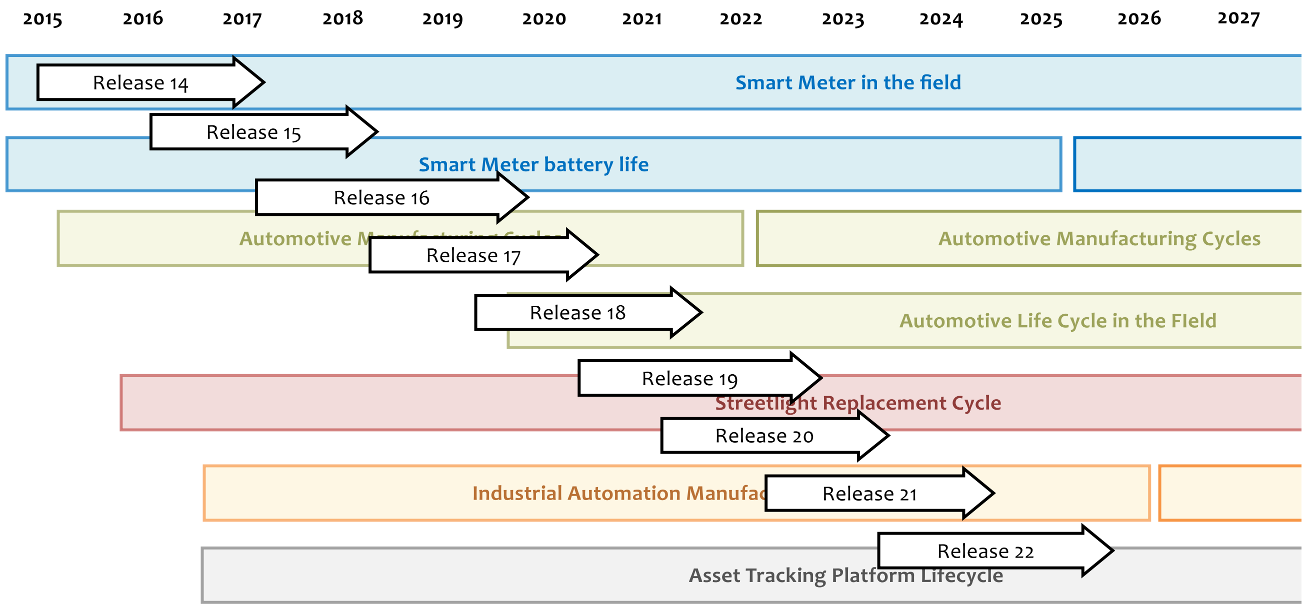

Figure 4 The Life Cycle of IoT products doesn't match with the 3GPP standards cadence

Source: Mobile Experts

The uncertainty about connectivity changes has multiple impacts:

- Some customers are reluctant to invest, because they're afraid of future changes;
- The industry never reaches economy of scale with so many changes;
- Software platforms and other products not related to connectivity cannot be optimized due to constant changes in connectivity.

Overall, we believe that a rationalization of life cycles is in order. LoRa, 802.15.4, and PLC proponents understand the need for long term, stable standards. Other wireless cheerleaders need to reorient their companies to support long product life as well.

DRIVERS IN KEY VERTICAL MARKETS

Some vertical markets are clearly well established, and enterprises have already made billion-dollar capital investments that will prevent any change in platforms or connectivity. Established markets include:

- Smart Meters
- Automotive Telematics
- Fitness Tracking Devices

A few vertical markets are well established with a wired technology, and are expected to adopt wireless alternatives. In most cases, the switchover to wireless has not happened yet, as the reliability and/or latency of the wireless approach causes too much uncertainty for the industrial user.

- Building Automation
- Factory Automation
- Security Sensors and Cameras

A third group of vertical markets are still emerging from the chaos of the creative phase, and the cloud platforms and connectivity are still in question. These areas are still up for grabs:

- Asset tracking
- Consumer white goods
- Agricultural sensors
- Drone operations

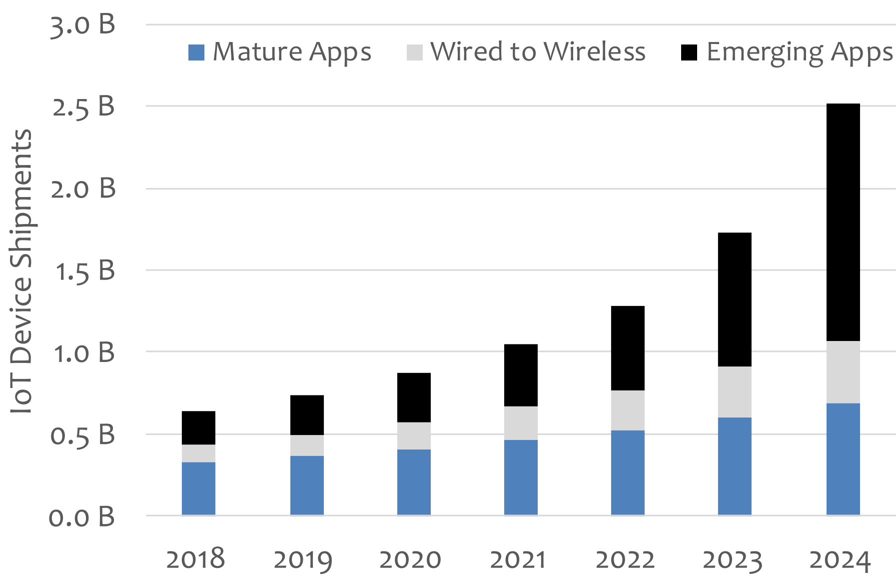

Chart 5: IoT Device Forecast by Level of Vertical Market Maturity: 2018-2024

Source: Mobile Experts

Over the next ten years, we expect many of the emerging IoT vertical markets to settle on a consensus connection technology, as well as Cloud platforms and business models to support each unique vertical business area. Many new areas such as drones are very likely to use Cellular IoT, but need a more stable API, roaming arrangements, and Cloud platforms to be mature before it can grow.

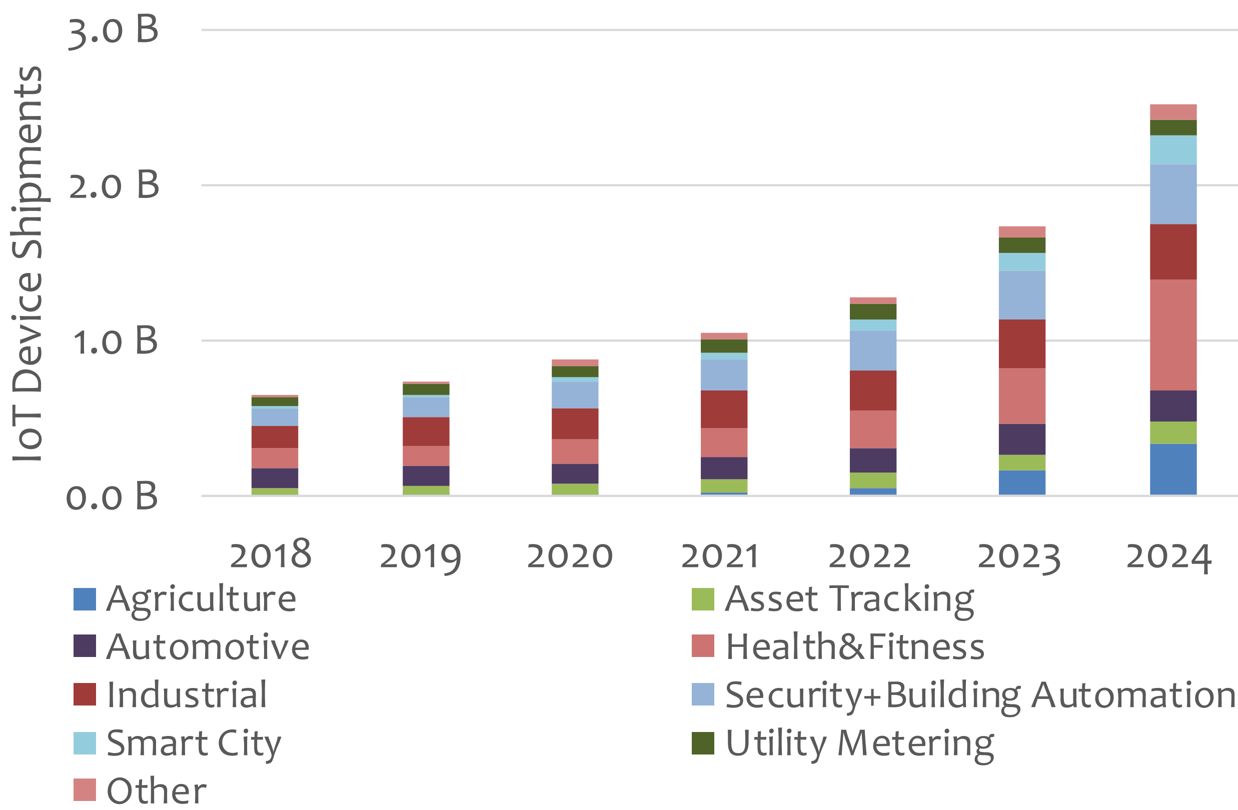

Chart 6: IoT Device Forecast by Market Area: 2018-2024

Source: Mobile Experts

When we forecast shipments of devices broken down by application area, the Agriculture, Health & Fitness, and Security/Building Automation areas appear interesting. But the dollar value of these markets is low and the opportunity for cellular technology can be limited. The lower volume application areas such as Industrial IoT can be lower numbers of devices with much higher dollar contribution.

Market Segment	Tech Priorities	Maturity Level	Cost Tolerance	Comments
Agriculture	Coverage	Emerging	Low	Cell coverage often not available
Asset Tracking	Widespread coverage Ad-hoc indoor coverage	Some existing apps, but 90% of market potential untapped	Low to Mid	Low cost opportunities, some APIs are in place
Automotive Telematics	Widespread coverage, Low cost	Established but needs migration from 2G/3G to LTE	High	Infotainment drives high bandwidth requirements
Automotive V2X	Reliability, Compatibility, Cost	Emerging	High	Market is migrating toward C-V2X but very slowly
Building Automation	Long range/ penetration Unlicensed operation	Established with wires and separate systems	Low	No consensus on a common platform. API support is weak
Healthcare	Battery life Security	Emerging	Low to mid	Patient monitoring could be a disposable item with huge volumes. No common APIs
Home Automation	Low Cost	Early stages	Very low	Struggle for platform dominance
Industrial	Various	Well established with Ethernet/Fieldbus	Mid to high	Competing with wires in many cases
Smart City:	Long range	Emerging	Low	Silos are developing, may not converge on horizontal platforms
Smart Meters	Long range	Electric meters mature; water/gas still developing	Mid	Platforms becoming mature this year

Figure 5 IoT Market Areas, Product Priorities, and Market Potential

Source: Mobile Experts

3 TECHNOLOGY OPTIONS

CONNECTIVITY

Connectivity was the key question for IoT in the 2016 timeframe… but most companies involved in developing a new application have decided on their connectivity, and now they're focused on higher levels of the stack. Here's a recap of our commentary on connectivity:

Mobile Experts is tracking more than 70 different technologies for connecting an IoT device. This incredible diversity has resulted from markets acting independently, each asking for different technical priorities. So far, a few of them appear to be dropping away, but at least 40 different connection options will remain.

Connectivity options fall into a few categories:

- Wired data protocols (Ethernet, Fieldbus, etc)
- Power Line Communications
- Short range wireless
- Unlicensed LPWA
- Licensed Narrowband RF
- 3GPP based wireless
- Satellite

None of these categories will disappear, because each of them satisfies a segment of the market with regard to multiple differentiators. We have identified six primary factors that create unique market niches, and listed them here in order of market impact:

1. Range: Distance and global coverage are usually the first criterion for selecting connectivity options;
2. Data Speed: The capability to carry data varies from kilobits per second to gigabits per second can dictate the type of technology to be used.
3. Battery Life: Some devices are powered, in automotive, electric meter, and industrial settings. Other devices need batteries to last for days, weeks, or even years… and this can be one of the primary factors.
4. Cost: The acceptable cost for the device and for related connectivity services will always be a factor for any application.
5. Reliability: The availability of a connection is usually a secondary consideration, but in some industrial applications this can become critical.
6. Latency: The total time to make a connection and respond with data can be critical in industrial cases, but not in many other apps.

Note that last year, we also listed "Functionality" –or the ability to handle two-way data as well as software updates on the fly—as a primary differentiator. In comparing IoT devices to RFID and other non-IoT connected devices, we still think that this is important. However, we have removed this differentiator from our list, as the IoT formats that don't support FOTA (Firmware over the air) updates have been clearly rejected in the marketplace.

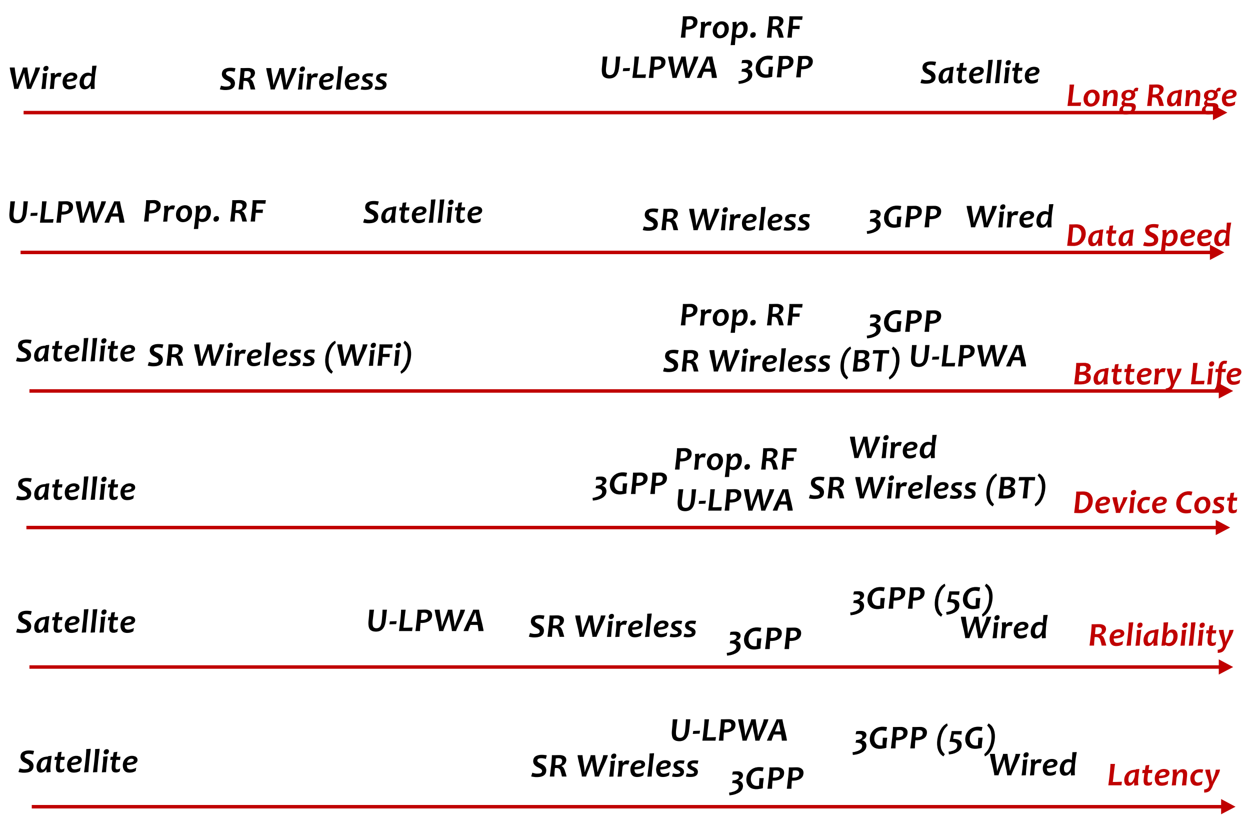

Figure 6   Differentiating Factors in IoT Market Development

Source: Mobile Experts

Based on these six main differentiating forces, we anticipate that markets will emerge with combinations of differentiators that are important. Examples include:

--The market for factory automation requires very low latency for robotic control, and very high reliability to assure non-stop operation. For this market, Ethernet or 5G connectivity will be preferred in premium cases. Wi-Fi could be used for some other cases, but in fact most factories prefer Ethernet cabling over Wi-Fi.

--Asset tracking for shipping containers requires connectivity on the oceans. Clearly, only satellite communications can provide the link required.

--Fitness devices require low cost, but can accept short range and low data speed. Short-range wireless options such as Bluetooth and ANT+ are ideal.

--Smart water meters need to transmit data from underground locations for miles, with battery life of 10 years. Only NB-IoT (3GPP based LPWA) and U-LPWA are viable candidates.

As you can see in the four examples listed above, major market segments have extremely different requirements, and using a single format for connectivity would be impossible.

The key to forecasting IoT connectivity is to recognize the markets where the top 2-3 differentiators align… and determine the possibility for a consensus to emerge on technology.

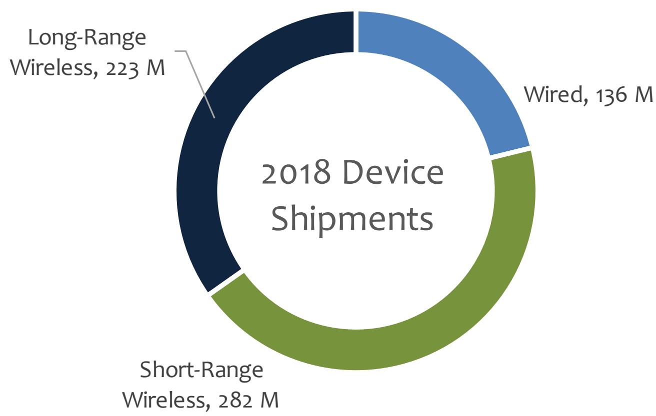

Chart 7: 2018 IoT Shipments: Segmented by Connectivity Type

Source: Mobile Experts

In each market area, we see a "category" of IoT connectivity rising to the top, and then the competition within the category is direct, with winners and losers. For example, within the Unlicensed LPWA market, Sigfox and Ingenu have failed to reach high volume, while LoRa has reached a level of tens of millions of devices per year. Sigfox and Ingenu no longer have the ability to catch up in terms of economy of scale. They may survive by focusing on secondary differentiators (such as support for key vertical markets) and shipping in lower volumes.

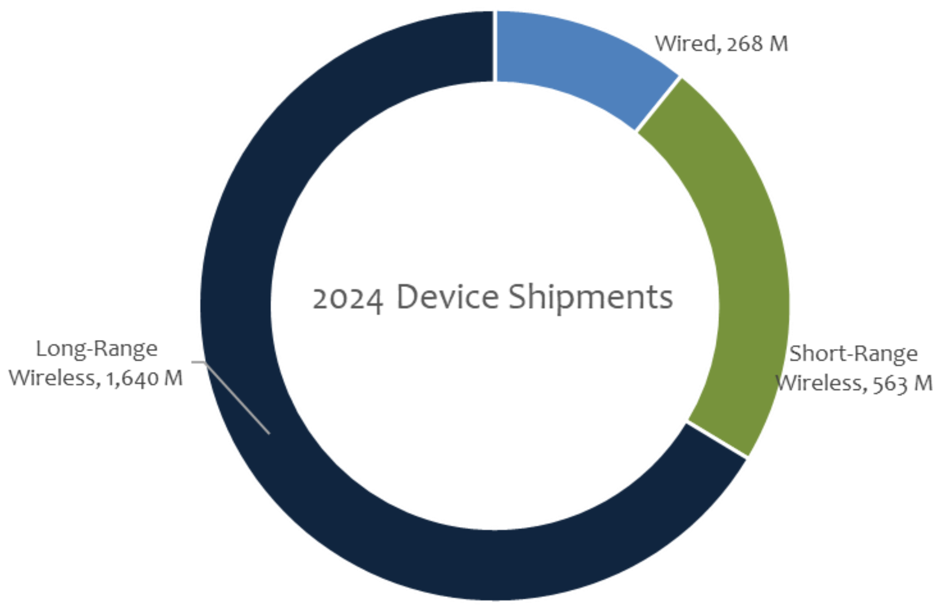

Chart 8: 20234 IoT Shipments: Segmented by Connectivity Type

Source: Mobile Experts

Mobile Experts covers the competition within the LPWA market and other specific technologies in our focused reports. The point that we're making here is that each of these market segments for connectivity will grow according to the growth of corresponding vertical markets. In general, we see some mature markets such as wired IIoT doubling over five years, while various wireless approaches will grow by 4x to 12x.

EVOLUTION OF COMPUTING PLATFORMS:

One key characteristic of an IoT device is that on-board computing is available to analyze data, summarize information, and package the information for transmission to the Cloud. In some cases, the data collection and on-board processing will be minimal. For example, moisture sensors in a farmer's field will simple report the current moisture level twice per day.

In other cases, the on-board platform will execute some heavy computing tasks. Automotive telematics involves a great deal of analysis of engine diagnostics, before reporting some simple information about maintenance issues.

Each application has a different balance of computing in the device, in the network edge, and in the central Cloud:

- Should the sensor platform in the farmer's field analyze moisture data, or just send the data to the Cloud? Clearly the answer is to send data for central processing, so that a map of multiple sensors can create a clear picture. Analysis at the sensor location would require local storage of data, as well as transmission of data from other neighboring sensors. Clearly localized analysis would require an upgrade to the computing platform (a cost issue) and a large increase in data transmission (a battery issue).
- Should an automotive platform analyze the clarity of oil, prompting a message only when the oil becomes cloudy and requires a change? Or should the car send raw data on oil cleanliness constantly? In this case, clearly the analysis should be performed on board, because computing power and electrical power are available. Minimizing data load is preferable because the analysis on this simple metric does not require a supercomputer.
- One more example: To perform facial recognition on security cameras, should the processing take place on the camera platform, or in the cloud? In this case, putting a high level of horsepower and storing a library in the camera platform would be costly, both in terms of money and electrical power. Battery-based cameras (on motion sensors) would be impractical. Instead, transmitting the huge stream of HD video up to the Cloud would be preferable, so that a centralized computer can handle the heavy lifting. This type of case actually brings up interesting compromises, where the local camera platform may improve data efficiency by cropping the videos or performing some pre-processing of the video stream.

Another aspect of computing trends relates to the use of local storage vs. centralized storage. Accessing a hard drive can require about 10 milliseconds for a small set of data. Now that 5G connectivity has started to enter the market, it's possible for the data connection to provide data as quickly as a hard drive. At the same time, the cost of flash memory is dropping quickly to a level of roughly $0.08/GB currently. Do these trends change the long-held tradition of keeping the processor and the memory in the same location? It's possible that a database of information can be kept at a network location, and accessed by individual IoT devices.

EDGE COMPUTING AND ITS IMPACT

Optimized computing is key to IoT development, and Edge Computing is important for low latency applications. Let's make sure that the distinction is clear.

Applications such as bike sharing applications don't need real-time computing. Tracking the bikes can be done roughly every 10 seconds… and speeding up the response time for the app will result in practically zero improvement in the revenue picture for the bike sharing company. So we expect most applications (asset tracking, building automation, smart meters, healthcare apps, and even most automotive use cases) to be non-realtime stacks that rely on some computing in centralized, hyperscale Cloud data centers.

The applications that need real-time computing (robotics, urgent map updates to cars, critical utilities, facial recognition, drone video analytics) require low latency---as we define it, latency below 50 msec—to succeed. In these applications, sending data back to a hyperscale data center 1500 miles away will take too much time, and there's a loss of control in the robotics or other physical thing which will be unacceptable. So, somebody needs to invest in Edge Computing servers and software that reside closer to the user. The network needs to separate the Control Plane and the User Plane for quick response time to user traffic. In these, cases, Multi-access Edge Computing (MEC) is a major architectural step away from Cloud Computing, where local computing resources can be used in conjunction with the Cloud to optimize in multiple dimensions (cost, latency, reliability).

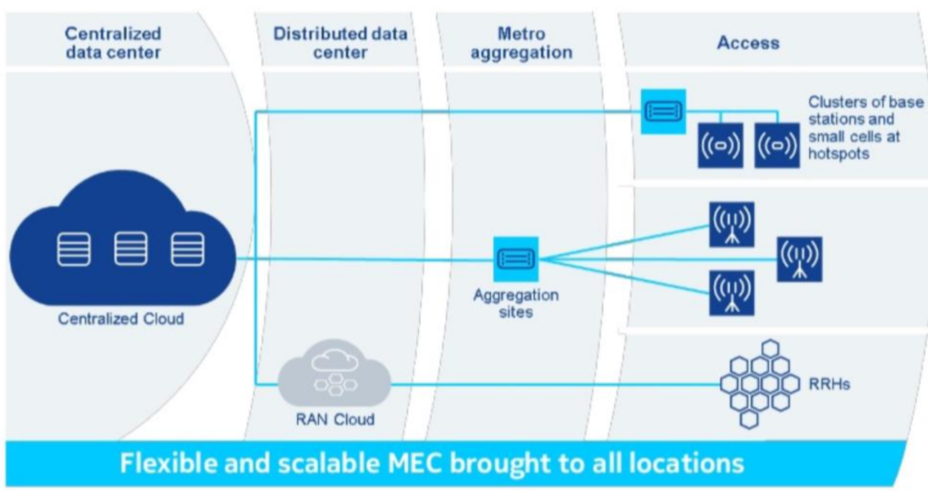

Figure 7 Multi-access Edge Computing at multiple locations

Source: Nokia

IoT Devices vs. "Connected Devices":

During the past 10 years, the number of simple connected devices has been huge, with 8-9 billion RFID tags used each year. We don't classify these as "IoT Devices" because they don't convey any information beyond their unique ID and the location of the reader device. But clearly in terms of asset tracking, the existing mainstream technology comes down to simple things like bar codes and RFID tags, not higher level IoT devices.

What does the future hold? We are expecting IoT devices to replace RFID for asset tracking in longer range applications. Shipping containers, fleet management, pallet tracking, and individual packages will be tracked by IoT devices that include a simple compute platform and wireless connectivity with an active transmitter.

Does that mean that the RFID market is dead? Not by a long shot. We see continued growth for RFID and other simple forms of tracking within the enterprise. But more advanced platforms are necessary to fill in the gaps: Bluetooth and Wi-Fi in retail, LPWA for agriculture, cellular for wide-area coverage, and satellite coverage worldwide.

Instead of viewing IoT as competing with RFID, we see the addition of IoT as another step toward a mature market for tracking items.

4 MAPPING MARKETS TO TECHNOLOGIES

BUSINESS MODEL SEGMENTATION:

The best business model for IoT will be very different according to the unique characteristics of value for each application. In some cases, key characteristics of the connectivity are important (throughput, range, or latency). In other cases, the computing aspect is important (facial recognition), with little demand on the connectivity side.

Clearly, the IoT market is too broad for a single business model to apply.

We are tracking three basic business models:

1. **Consumer**: End-user devices with a personal purpose (such as tag tracking or fitness monitoring) have a business model that tracks along with other consumer services. The user would sign up for a Cloud-based service and any hardware would be tied to their account. The information (tracking data, fitness data, etc) would be viewed via the Cloud service over the Internet. In general, these applications would not justify the use of Edge Computing because the value of realtime computing would be low… and nobody will pay for deployment of local server resources. In this business model, the apps don't require a monthly account with a service provider because data is generally shared over a local broadband service "over the top" or OTT.
2. **Service Provider**: Devices that use higher levels of data connectivity or mobility on a public network tend to be forced into business models that conform to the operator's preferred approach. When it comes to tracking FedEx packages or rental bikes, a U-LPWA or cellular network will be chosen as the platform for connectivity. The communications service provider (CSP) will take a leading role because they control a key link in the technical chain, but also because they already have a relationship with the end customer and can add an IoT charge onto an existing bill.
3. **Enterprise**: Many large enterprises prefer to own their infrastructure, instead of relying on a service provider. Major utilities, airlines, and manufacturing operations tend to move in the direction of making the capital investment to set up their own infrastructure and devices. In some cases the enterprise can bring in the CSP for global roaming relationships If wide-area coverage is required, or global roaming is important, then the enterprise may engage with a mobile operator directly. Otherwise they are likely to implement an internal network.

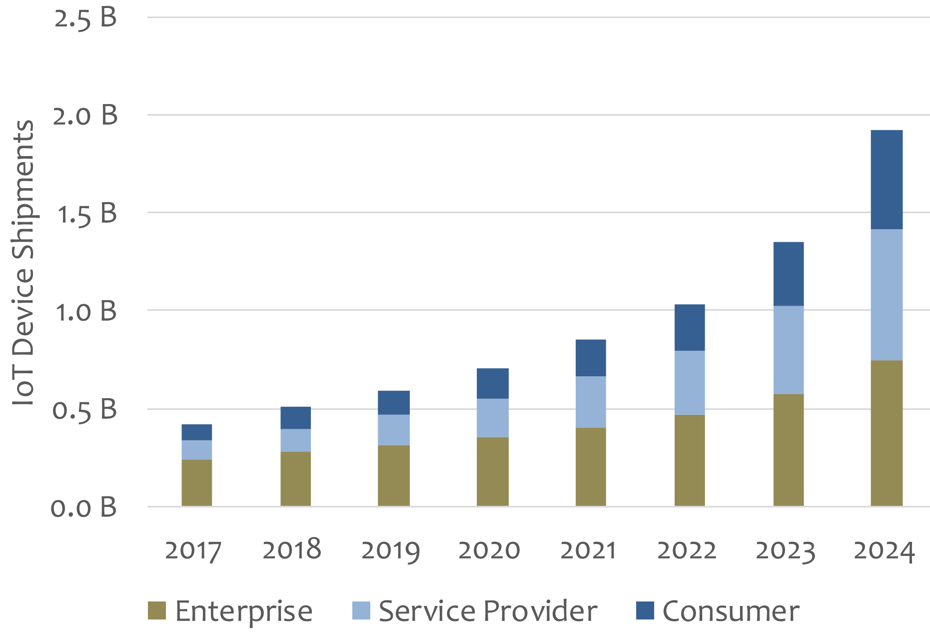

Chart 9: IoT Shipments: Devices by business model structure, 2017-2024

Source: Mobile Experts

5 IoT Revenue Outlook

Service Revenue:

Only a fraction of the overall IoT market involves a service provider charging a monthly fee. Of course, the Bluetooth fitness devices and consumer asset tags don't involve any "service revenue", so the potential here is for higher-level IoT devices that involve long-range networks or specialized connectivity or computing of some kind.

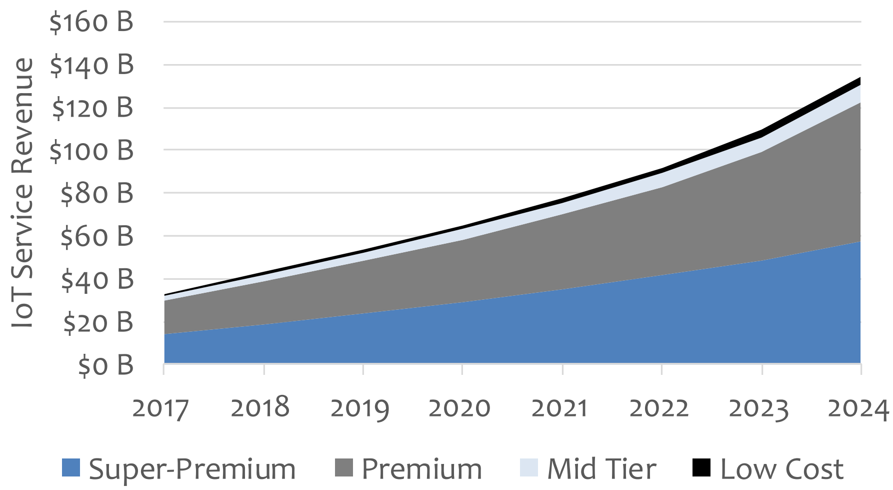

Chart 10: IoT Service Revenue, 2017-2024

Source: Mobile Experts

The dominant areas in terms of revenue impact will be the "Super-Premium" and "Premium" segments, with monthly service fees in the range of $20 to $1,000. In other words, the revenue from automotive and industrial applications will be much more meaningful than the revenue from simplistic devices in large quantities. The mobile operators are not good at this business model, so these premium opportunities (such as drone video analytics) may require some time for the mobile operators to create business units with sensible sales channels, as well as practical Edge Computing platforms with software that suits the application. That's why we are forecasting limited growth for services revenue (only $140B) through 2024.

Device Revenue:

One step lower in the food chain, when we look at devices it's clear that enterprise devices will drive far higher revenue than the consumer devices we see today. In particular, healthcare, fleet management, insurance, and asset tracking applications will be dominated by enterprises. Fitness and home automation will remain in the consumer category, but device and service revenue for these segments will be fairly low.

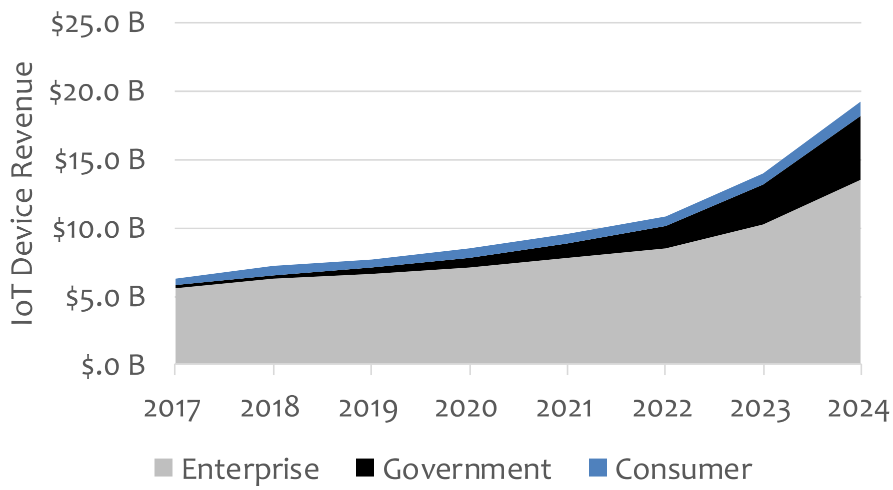

Chart 11: IoT Device Revenue, Enterprise vs. Govt. vs. Consumer, 2017-2024

Source: Mobile Experts

NOTE: Device Revenue refers to the connectivity device, not the entire platform (e.g. the module + antenna + battery + software, not the entire jet aircraft or car)

SEMICONDUCTOR REVENUE:

The steady growth in IoT devices will translate directly into steady growth for chip revenue. Excluding semiconductors related to infrastructure, the total semiconductor revenue (including only connectivity and on-board computing, not other electronics) will grow from $2.3B to more than about $6B in 2024. Note that we have removed RFID chip revenue from these totals since last year's forecast.

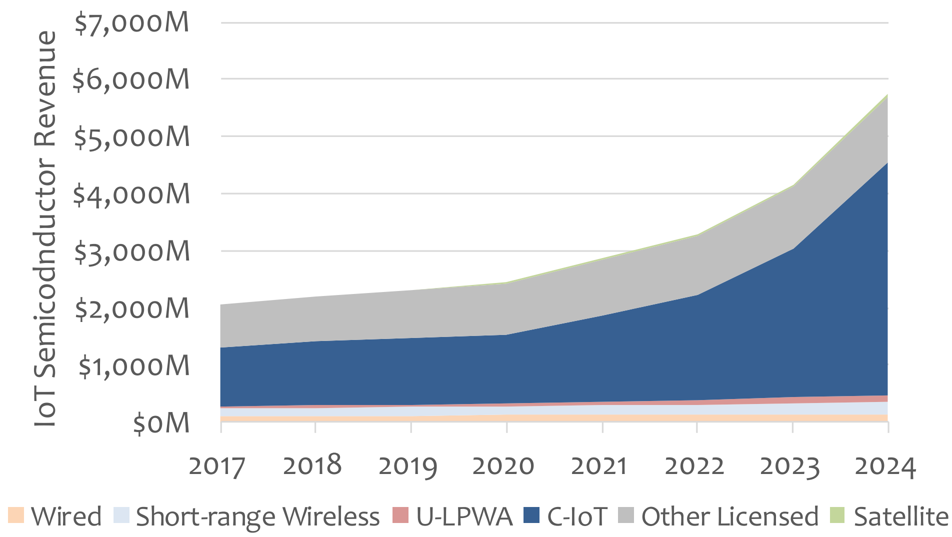

Chart 12: IoT Semiconductor Revenue, by connectivity format, 2017-2024

Source: Mobile Experts

NOTE: Including semiconductors for connectivity and on-board computing only

6 INSTALLED BASE OUTLOOK

INSTALLED BASE:

Today, a large percentage of the connected devices that are in use are passive RFID tags. These are used for a month or so, and then in most cases they are thrown away. Many of the headline numbers that point to "50 billion connected devices" are including the 10 billion RFID tags shipped every year, with generous assumptions about long-term use in the field.

In our overall tracking, we keep "Connected devices" such as RFID separate from the IoT market, so we are tracking to a total of about 16 billion "Connected devices" in 2024, or 8 billion IoT devices.

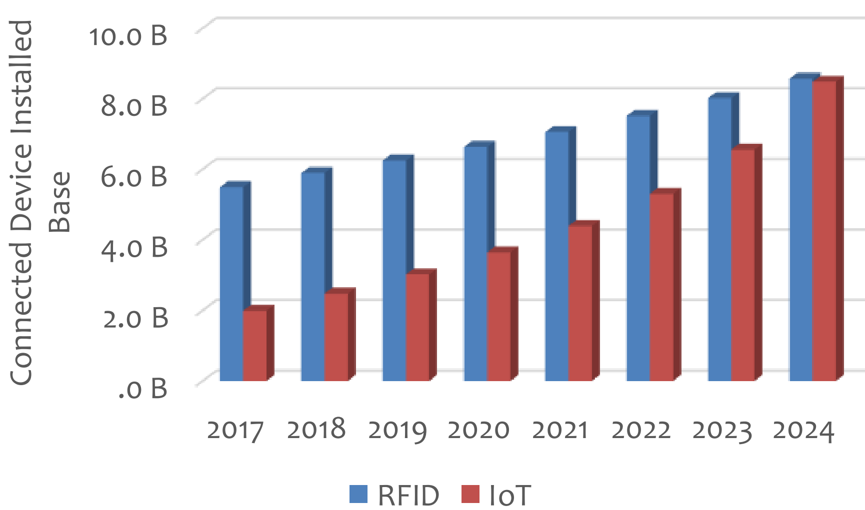

Chart 13: IoT Installed Base, 2017-2024

Source: Mobile Experts

7 BREAKDOWNS OF IOT DEVICE SHIPMENTS

OUTLOOK BY CUSTOMER TYPE:

Consumer applications were the first area of development for IoT… perhaps naturally because the smartphone business is, at its core, a consumer market. In terms of the number of devices used, consumer areas grew quickly. However, over time we expect that enterprise devices will overtake the consumer market.

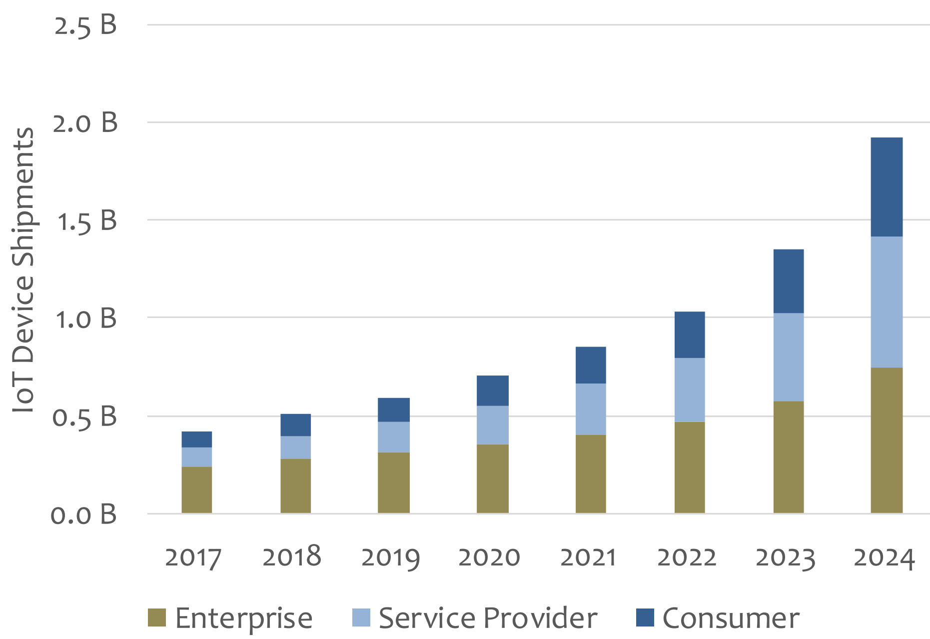

Chart 14: IoT Device Shipments, by end customer type, 2017-2024

Source: Mobile Experts

OUTLOOK BY LEVEL OF MOBILITY:

Short-range devices go along with the consumer business model, but new connectivity (LoRa, NB-IoT, Cat-M) has come into play that allows for long range, mobility, and long battery life at the same time. The short-range devices use simple, local compute platforms and don't need to access the Cloud in some cases. In other cases, the Cloud affords a simple and powerful user interface for the short-range Bluetooth devices or smart-home devices.

In the mobile applications, growth will take off over time, but the combination of a mobile network and a Cloud platform will take more time because it's a more complex business model.

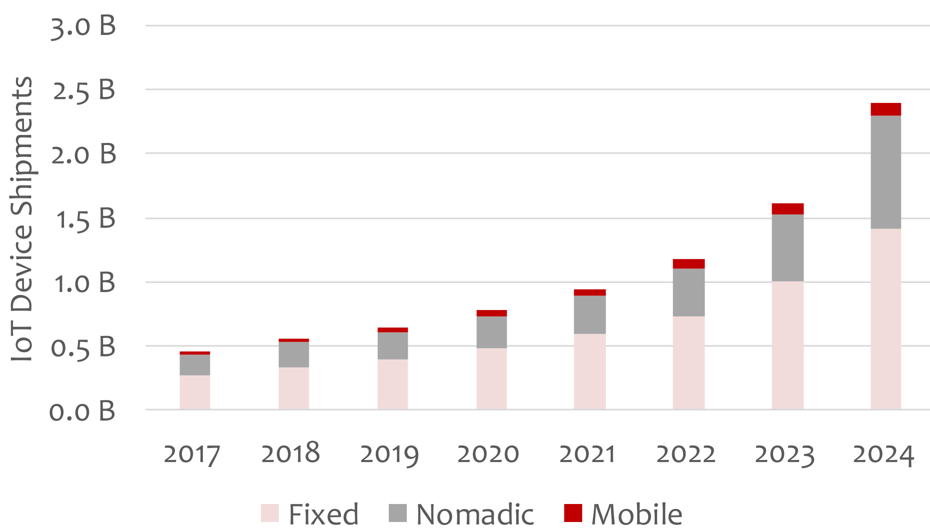

Chart 15: IoT Device Shipments, Fixed vs. Nomadic vs. Mobile, 2017-2024

Source: Mobile Experts

OUTLOOK BY PRICE TIER:

While huge numbers of devices will be used without any service revenue, we are now starting to build up a base of hundreds of millions of devices connected through a serviced network. We define segments by the price tier of connected devices, according to the service fee per year.

- Super-premium: $700 service revenue per year, $100+ module
- Premium: $100 service revenue per year, $50+ module
- Mid-tier: average of $5 service revenue per year, $20 module
- Low Cost: average of $2 service revenue per year, $10 module or less

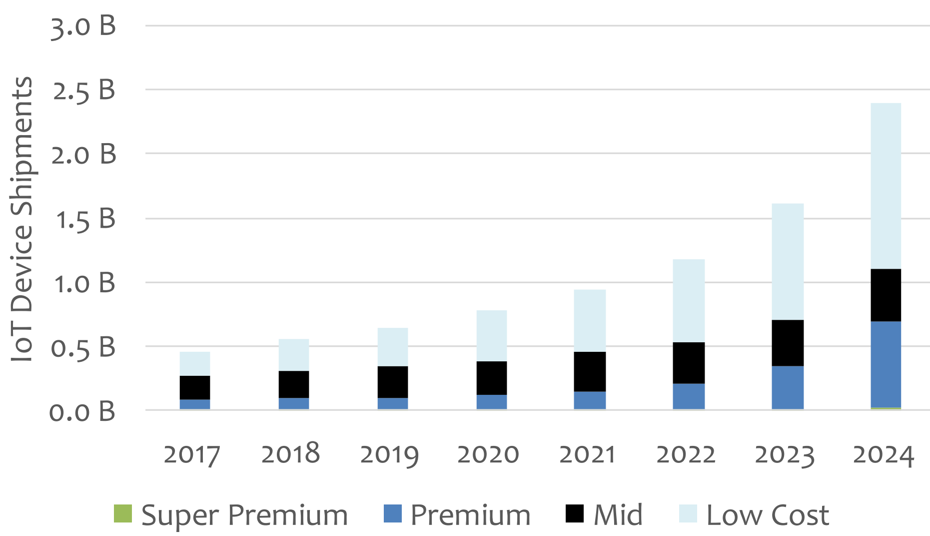

Chart 16: IoT Device Shipments, by Pricing Tier, 2017-2024

Source: Mobile Experts

OUTLOOK BY BATTERY LIFE REQUIREMENTS:

The majority of IoT devices require long battery life in order to be useful. Smart meters, industrial sensors, and building automation devices such as door alarms must work on a lifetime greater than one year. Other devices such as fitness trackers can be charged every few days. And of course a third class of devices has access to cheap electrical power, including automotive and most industrial applications. We expect long battery life to become table stakes for the majority of applications over time.

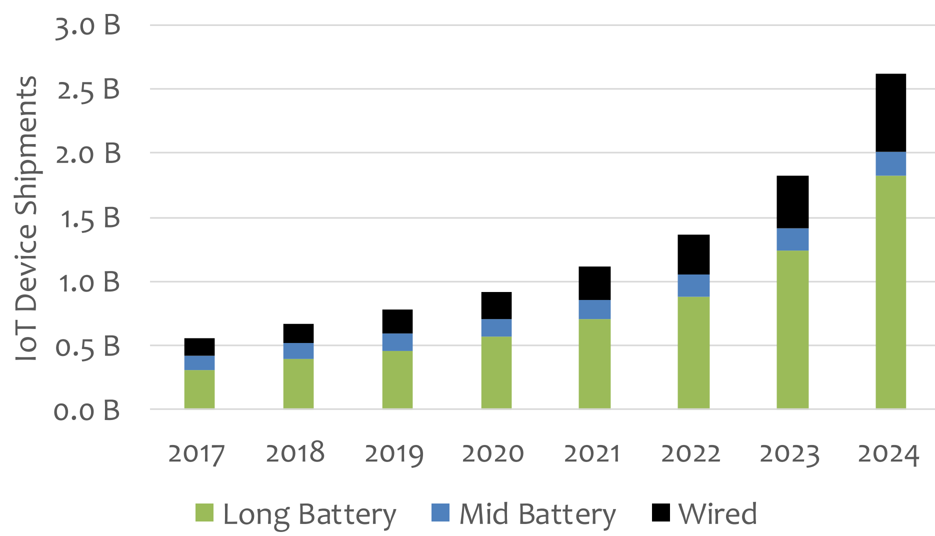

Chart 17: IoT Device Shipments, by Battery Requirement, 2017-2024

Source: Mobile Experts

Note: Long battery life defined as greater than 2 weeks

Outlook by Data Rate Requirement:

The designer has a choice with an IoT device: Either handle computing and analytics on-board the device, or transmit large streams of data back through the network for analysis. Most IoT devices only spit out bursts of 1 kB at a time… whether on-board computing is used or not, there's not much data involved. However, video analytics, voice connectivity, video, or other real-time requirements drive a need for higher data rate, and as capacity and density of devices grows, the spectral efficiency requirement on the network will become more important. The high end could extend up to 1 Gbps in some cases such as real-time data communications of raw sensor data on autonomous vehicles, or for software uploads/downloads. For the next five years, we see a greater focus on the lower speed data requirements.

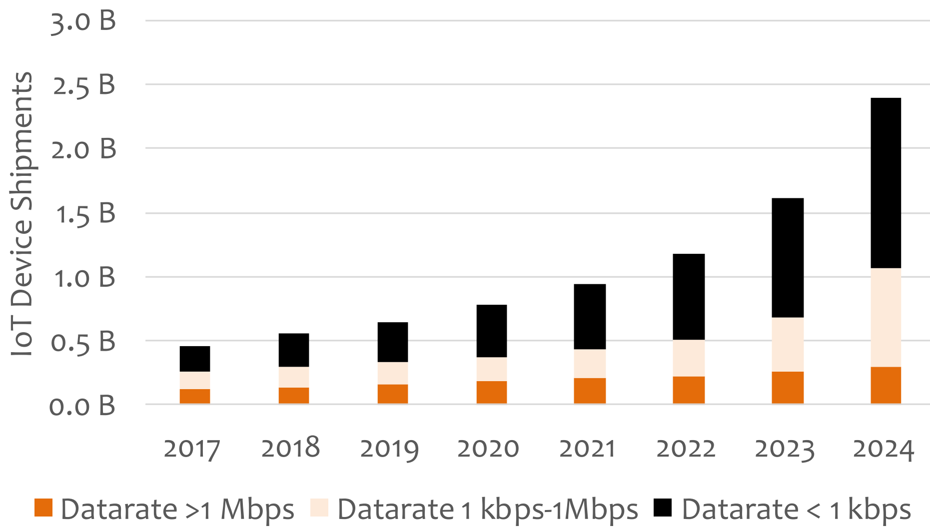

Chart 18: IoT Device Shipments, by Datarate Requirement, 2017-2024

Source: Mobile Experts

OUTLOOK BY COMPUTING ARCHITECTURE (ON-BOARD, EDGE COMPUTING, CLOUD COMPUTING):

Each application will have a different tradeoff in terms of choices between on-board computing, edge computing in the network, or centralized cloud computing. Most IoT applications really don't need to transmit large amounts of data, and don't need real-time decisions to be made. So the majority of IoT devices (especially in the next five years) will not use Edge Computing. However, over time, we expect that applications for premium industrial use cases will require heavy analytics and real-time computing, which in many cases will outstrip the capability of the on-board platforms. In those cases, on-premises Edge Computing or "far edge" MEC in a public network will come into play.

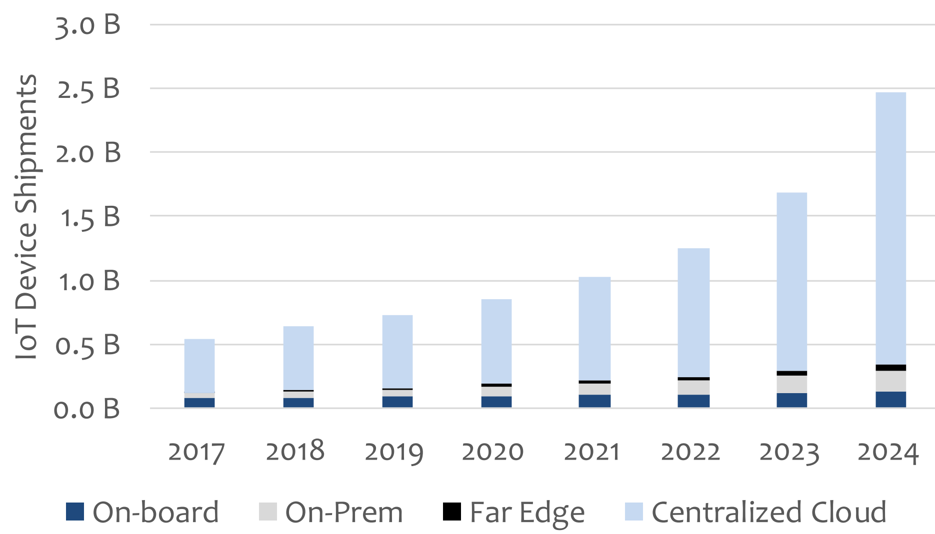

Chart 19: IoT Device Shipments, On-Board vs MEC vs Cloud Compute, 2017-2024

Source: Mobile Experts

8 ACRONYMS

10-BASE-T: The physical media for Ethernet involving twisted pair copper wire
100-BASE-T: The physical media for 100 Mbps Ethernet on copper wire
2G: Second Generation Cellular
2x2 MIMO: Two transmitters and two receivers
3G: Third Generation Cellular
3GPP: Third Generation Partnership Project
4G: Fourth Generation Cellular
4x4 MIMO: Four transmitters and four receivers
5G: Fifth Generation Cellular
5G NR: 5G New Radio – the expected frame structure for 5G communications
6LoWPAN: IPV6 over Wireless Personal Area Networks
802.11: The IEEE working group for unlicensed local-area networks
802.11n/ac: IEEE standard for general wireless computer networking
802.11af: An IEEE standard for unlicensed networking in TV white space frequencies
802.11ah: IEEE standard for machine-to-machine networking below 1GHz
802.15.4: An IEEE standard which specifies PHY and MAC for low datarate personal area networks
802.3: An IEEE standard for wired (Ethernet) computer networking
8T8R: Eight Transmitters and eight receivers
AES-128: Advanced Encryption Standard-128 bit
AMI: Advanced Metering Infrastructure (two-way)
AMR: Automated Meter Reading (one-way)
ARIB: Association of Radio Industries and Businesses
BLE: Bluetooth Low Energy
Bps: bits per second
BPSK: Binary phase shift key modulation
BT: Bluetooth
CCM: Constant Coding and Modulation
CENELEC: European Committee for ENectrotechnical Standardization
C-IOT: Cellular IoT
CSS: Chirp Spread Spectrum
C-V2X: Cellular Vehicle-to-Other communications
DASH-7: A protocol used for 433 MHz ISM band communications for RFID
dBm: A measurement of radio signal strength
D-BPSK: Differential binary phase shift key modulation
DSSS: Direct sequence spread spectrum
EC-GSM: Extended coverage GSM
EDGE: Enhanced Data for GSM Evolution
eDRX: Extended discontinuous reception
eGPRS: Enhanced General Packet Radio Service

FCC: Federal Communications Commission (USA)
FHSS: Frequency hopping spread spectrum
FSK: Frequency Shift Key modulation
G3-PLC: A standard for Power Line Communications
Gbps: Gigabits per second
GFSK: Gaussian Frequency Shift Keying modulation
GHz: Gigahertz
GMSK: Gaussian Minimum Shift Keying modulation
GPRS: General Packet Radio Service
GPS: Global Positioning System
GSM: Global System for Mobile (2G cellular standard)
Hz: Hertz
IIoT: Industrial Internet of Things
IoT: Internet of Things
IPv6: Internet Protocol version 6
ISA100.11a: A wireless standard developed by the International Society of Automation
ISM: Instrumentation, Scientific, and Medical (a designation for unlicensed spectrum)
Kbps: kilobits per second
kHz: Kilohertz
LAN: Local Area Network
LoRa: Long Range (a low power, wide area wireless format)
LPWA: Low Power Wide Area communications
LTE: Long Term Evolution (a 4th generation cellular standard)
M2M: Machine-to-machine communications
MAC: Media Access Control
Mbps: Megabits per second
MEC: Multi-access Edge Computing
MHz: Megahertz
MIMO: Multiple input, multiple output
MTC: Machine-type communications
MU-MIMO: Multi-user MIMO
mW: milliwatts of power
NB-IoT: Narrowband IoT (a 3GPP based wireless standard)
NFC: Near Field Communications
PAN: Personal Area Network
PMP: Point to multipoint communications
OOK: On-off keying modulation
O-QPSK: Offset Quadrature phase shift keying modulation
OFDM: Orthogonal frequency division multiplexing
PC: Personal computer
PHY: Physical layer
PLC: Power Line Communications
PRIME: PoweRline Intelligent Metering Evolution (a PLC standard)
QAM: Quadrature Amplitude Modulation
QPSK: Quadrature Phase Shift Keying modulation

RFID: Radio Frequency Identification
RPMA: Random Phase Multiple Access
RTLS: Real-Time Location System
SRD: Short Range Devices
TDMA: Time Division Multiple Access
TTI: Total Time Interval
TVWS: Television White Spaces
U-LPWA: Unlicensed Low Power Wide Area
UWB: Ultra-wideband technology
V2V: Vehicle-to-vehicle communications
W-CDMA: Wideband Code Domain Multiple Access, a 3G radio interface
WAN: Wide Area Network
Wi-Fi: Wireless Fidelity (refers to the broad family of 802.11 standards)

9 METHODOLOGY

For this broad overview of the IoT market, Mobile Experts relied on a wide variety of sources. This report was compiled from the data collected for more than 10 other research studies in IoT.

Our first step was to examine "horizontal" technology studies on LPWA and Cellular IoT, with a focus on technical comparisons of range, battery life, capacity, device density, and cost.

The second step was to investigate specific vertical markets, with a 60-page analysis of each:

1. Smart Meters
2. Asset Tracking
3. Health and Fitness IoT Devices
4. Automotive IoT Devices
5. Industrial IoT Devices
6. Building Automation IoT Devices
7. Smart Cities

In each of these individual reports, we interviewed more than 30 different companies, including suppliers, service providers, and end users. Therefore, for the ***Big Picture of IoT*** report the total number of interviews that are relevant has reached a level of at least 200 companies.

The forecast data were derived from:

- Direct input from semiconductor vendors regarding shipments of various IoT device types;
- Interviews with representatives from industry alliances for each technology area;
- Interviews with service providers, ranging from cloud service providers for enterprise IoT applications to mobile operators and vertically integrated service providers for IoT;
- Interviews with end users in each application area, such as GM, Ford, Toyota, GE, Siemens, Johnson Controls, Toyota, and Kaiser Permanente.

In addition to these sources of data, Mobile Experts used our previous technical comparison between multiple LPWA and LTE/NB-IoT formats as a foundation for the expected success in each application. The considerations of cost, range, capacity, and battery performance that were estimated in the Mobile Experts LPWA vs. LTE study were a firm, non-biased reference point to understand the expected product performance in each case.

DEFINITIONS:

Mobile Experts makes a clear distinction between "Connected Devices" , "IoT Devices", and "Human Interface Devices" due to the significant differences in architecture and function.

Connected Devices: All devices that connect autonomously to a network can be considered "connected devices". RFID tags without an onboard computing platform or an IP address can fit into this category.

IoT Devices: Our one-sentence definition of IoT focuses on the autonomous aspect of the networking, but narrows down the broader category of "connected devices" by limiting IoT devices to those which transfer data with significance beyond the simple ID of the device. To put it concisely:

"An IoT device incorporates sensing and/or actuation, networking autonomously, with the option for computing to reside at the edge, centrally, or both locations."

Human Interface Devices:

Mobile Experts has chosen to exclude the billions of devices which involve a human user. Remote controls, key fobs, smartphones, Bluetooth headsets, and other devices that offer convenience for a human user are not included as IoT devices in this report. Other wearable devices such as fitness trackers, that connect autonomously and share data for the benefit of a human user, are included as IoT devices because the connection and data sharing are done in the background without any human intervention.